ROGERS CORPORATION

Arlon Silicones Technology

Highly Thermally Stable Flexible Heater Compound
Arlon's 27CR (UL Recognized Flexible Heater Compound)

Introduction

The purpose of this application note is to describe the benefits of Arlon's highly thermally stable flexible heater compound. Arlon's UL recognized 27CR compound has improved thermal aging resistance that is superior to current products on the market. The 27CR compound and calendered flexible heater substrates have proven superior thermal aging resistance through rigorous analysis, including long term property retention during accelerated thermal aging. Long term thermal stability with good tensile strength and dielectric strength retention has been validated through a UL746B program, Polymeric Materials - Long Term Property Evaluations. The 27CR compound also shows superb short term resistance to excessive crosslinking, which leads to retention of flexibility in extreme thermal environments. Derivation of an Arrhenius equation through analysis of silicone coated flexible heater substrate adhesion strength, a key calendered substrate property, further validates compound longevity in high temperature environments. Thermal aging analysis of key material properties places the 27CR compound best in class versus leading competitors.

Most silicone flexible heater substrates will lose a large percentage of their initial post cured tensile strength, elongation, dielectric strength, and bond strength at elevated temperatures, especially at temperatures over 200^{o}C. Silicone inherently has superb thermal oxidative stability, but at extreme temperatures silicones can start to lose flexibility and strength. This occurs because of the excess energy being absorbed by the silicone from extreme temperature exposure. There are two main processes that occur that cause the thermoxidative breakdown at temperatures between 200-350^{o}C. Firstly, excessive crosslinking can take place, which will cause the silicone to lose its flexibility and become brittle. Secondly, pendant groups on the silicone polymer backbone can volatilize off the silicone compound, which can result in a loss of key physical properties. Finally, oxidation of the silicone forms silicon oxides [1]. Arlon's 27CR flexible heater compound is designed with thermo-oxidative stability in mind so coated substrates remain flexible. The 27CR compound and coated flexible heater substrates do not deteriorate as easily as the competition at higher temperatures, which results in minimum loss of key properties at temperatures in excess of 200°C.

Thermal Endurance

Thermal stability is a key characteristic of silicone flexible heater substrates because of exposure to a wide range of temperatures. Silicone coated fabrics and films can be rated for long term service up to 220^{o}C, and still maintain functionality with intermittent thermal exposure up to 320^{o}C. Silicone flexible heater substrates must be able to retain key material properties of tensile strength, elongation, dielectric breakdown strength, and adhesion strength at these elevated temperatures over long operation periods. The 27CR compound and coated substrates have been tested by Underwriters Laboratories and received a Relative Thermal Index (RTI) of

220°C/220°C (Electrical/Mechanical rating) under the UL Card E54153. The electrical RTI is associated with the critical insulating property of dielectric breakdown strength. The mechanical strength (Mechanical without Impact) RTI is associated with critical mechanical strength and structural integrity focuses on ultimate tensile strength. The Electrical and Mechanical RTI ratings were developed over a 1.5 year accelerated aging program with UL, in a systematic process to validate the high temperature stability of the 27CR compound and its associated calendered substrates [2].

Short Term Resistance to Excessive Crosslinking

While most silicone compounds will begin to excessively crosslink at temperatures higher then 200°C, which leads to a loss in tensile strength and elongation, Arlon's 27CR compound will retain these key properties better at higher temperatures than alternative silicones. The charts below show how Arlon's thermally stable flexible heater compound has better tensile strength and elongation retention compared to Arlon's 57 compound. Chart 1 shows that Arlons thermally stable compound does not lose tensile strength during short term exposure to temperatures over 250°C. The 27CR product retains over 95 percent of its tensile strength when exposed to temperature over 250°C for up to one week and has virtually no loss in tensile strength when subject to 320°C for 24 hours.

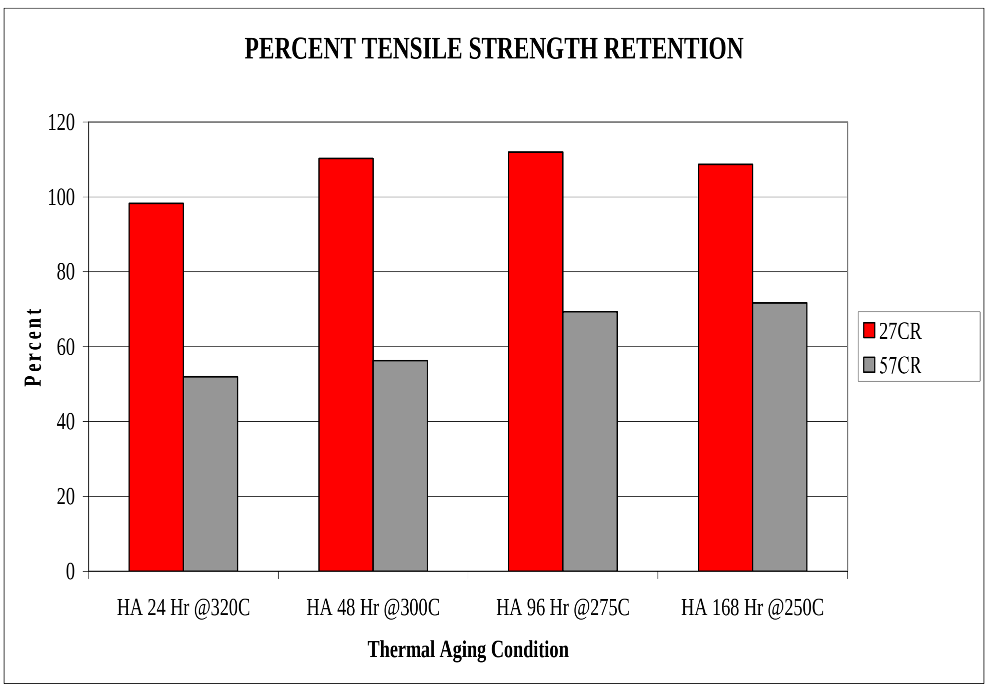


Chart 1

Chart 2 highlights how the 27CR compound retains over 30 percent of its initial elongation after 24 hours at 320°C . The 57CR compound retains less than 15% or its original elongation for this same thermal exposure period.

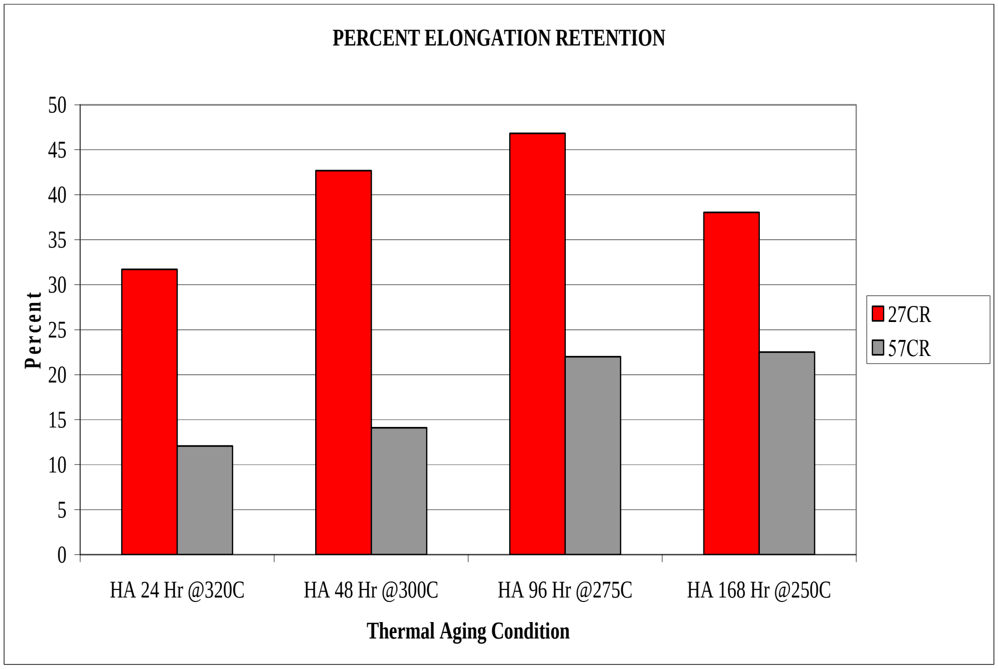


Chart 2

It is easy to see that the 27CR compound has a higher retention of elongation and therefore will remain flexible when subject to aggressive thermal spikes compared to the current industry best silicone compound.

The short term thermal aging study was performed on molded ASTM slabs to show how Arlon's 27CR compound can handle extreme temperature spikes much better than alternative products. The 27CR compound retains its tensile strength and elongation better than the alternatives and therefore retains greater elasticity or flexibility. This is critically important because as silicone products start to lose there flexibility, micro cracks can form, leading to field failures in final products. Alternative product functionality can be severely hindered if exposed to very high temperatures for short periods of time.

The photograph below really defines the retention in elongation for the 27CR compound versus 57CR compound when thermally aged for 24 hours at 300°C. After aging, an ASTM slab of the 27CR compound it can be easily folded 180 degrees without fracture (**Photo I**), which is exactly the failure mode for the alternative material (**Photo II**)

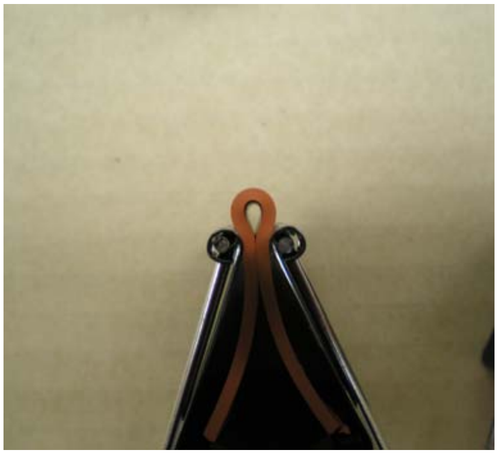


Photo I

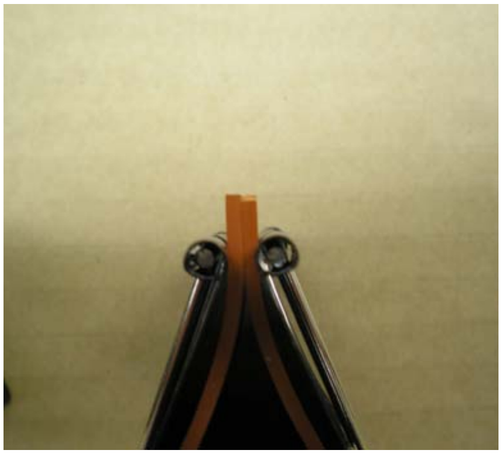


Photo II

Adhesion Strength Longevity

The 27CR compound shows excellent retention of fabric adhesion at elevated temperatures. The alternvative starts to lose adhesion strength to fabrics at accelerated rates versus the 27CR compound. The 27CR compound maintains cohesive failure at high temperatures and retains its level of adhesion strength longer. Chart 3 below compares adhesion strength to fiberglass fabric of the 27CR compound versus an alternative compound. The chart was developed using calendered ply adhesion coupons based on the 27CR compound versus a leading calendered product. The coupons were thermally aged under accelerated conditions so that an Arrhenius equation for bond strength could be developed. An arbitrary end of life ply adhesion strength of 1.5 pounds force per inch width was chosen to compare end of life in terms of compound adhesion to fiberglass fabric.

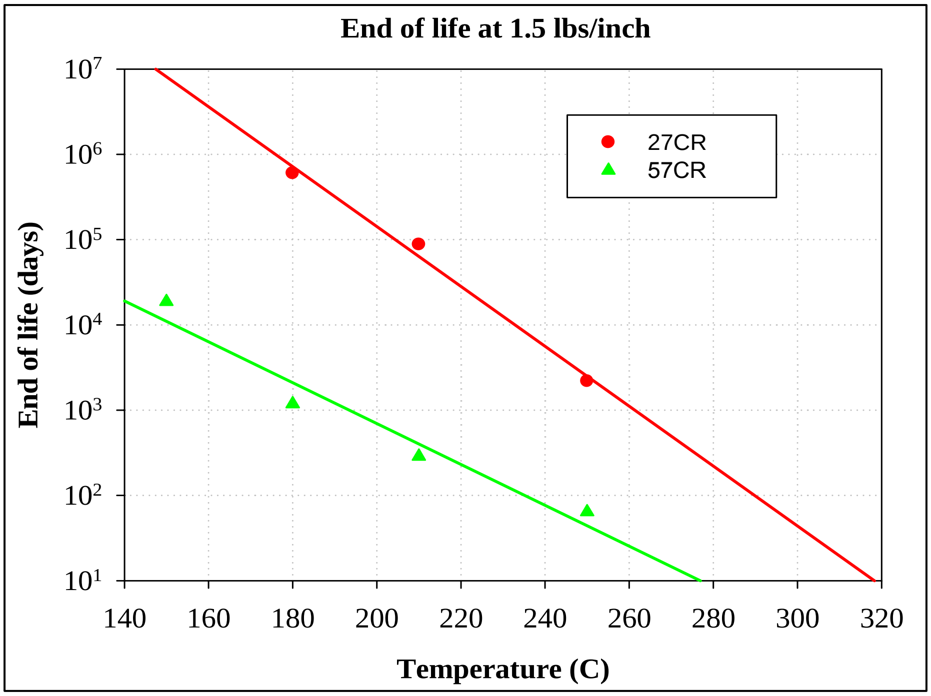


Chart 3
(Based on Side 2 to Side 2 ply adhesion coupons built from 55##9R028 constructions)

Chart 3 shows the 27CR based calendered substrates have extended operational life in terms of maintaining adhesion strength between 140°C and 320°C. Chart 3 can be read by choosing a temperature on the x-axis, moving vertically until intersecting either regression line, and then moving horizontally until intersecting the y-axis, which is the end of life in days for silicone to fiberglass adhesion. For example, the end of life in terms of bond strength at 220°C for the 27CR calendered substrates is an amazing ~30,000 days compared to ~225 days for the alternative. Since this study isolates the kinetics of polymer thermal aging (aerobically) and uses an arbitrary end of life value, the regression lines should be used with caution, but overall bond strength longevity of 27CR calendered substrates is considered superior. Another method of comparing the 27CR to the competition is a single thermal aging cycle comparison. Chart 4 shows the 27CR and alternative material aging at 210°C.

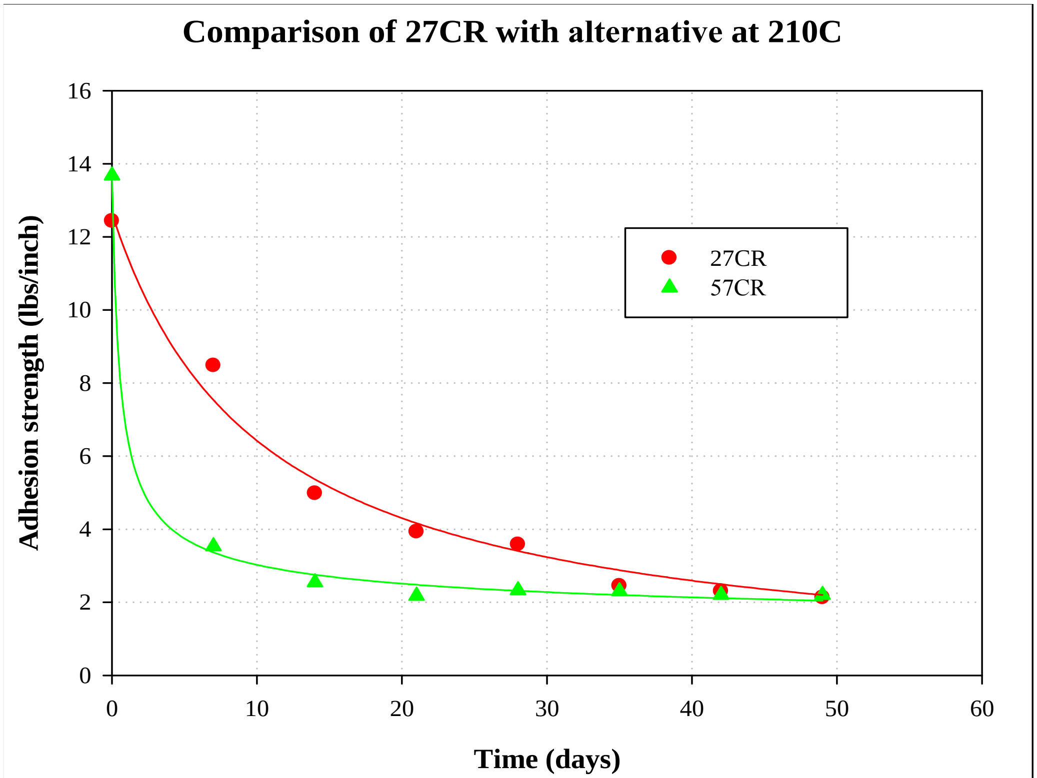


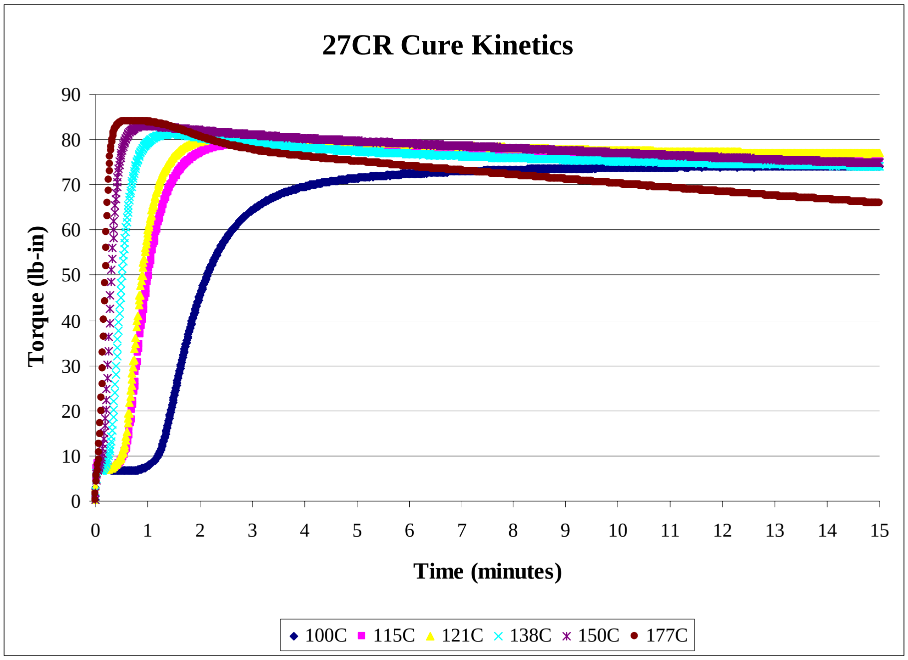
Chart 4

The chart shows the rapid decay in the alternative's bond strength at 210°C. In only a day at temperature, the 27CR based substrate has superior bond strength.

Long term adhesion strength of the 27CR compound to Stainless Steel 304 and Alloy 600 is also considered very good compared to the alternative. 27CR bases substrates will not fail adhesively from primed foil after long term aging and because the polymer is so thermally stable the overall foil laminate adhesion strength is superior to the alternative.

Bulk Compound and Calendered Substrate Processing

Chart 4 shows the cure kinetics of the 27CR compound and can be used as a reference for processing calendered substrates. As the 27CR product cures and polymer crosslink density increases and the Monsanto R100 Rheometer torque also increases. A torque reading of approximately 70 lbs-in is considered is considered a fully crosslinked polymer. This takes less then 5 minutes for all of the cure temperature rheometry curves in Chart 5.



Arlon recommends the following process parameters for building laminates from flexible heater substrates calendered with the 27CR compound:

- Platen Press Lamination (Uncured Silicone to Uncured Silicone)
    - Temperature: 121°C
    - Pressure 50 psi
    - Time: 5 minutes

- Vacuum Bag Lamination (Uncured Silicone to Uncured Silicone)
    - Temperature: 121°C
    - Pressure : 14.7 psi
    - Time: 5 minutes
        - Notes:
            - Laminate entrapped air must be completely removed
            - Substrate surfaces must be completely mated
            - Time equals the time that the polymer is at temperature

- Platen Press Lamination (Uncured Silicone to Primed Foil)
    - Temperature: 100°C
    - Pressure: 50 psi
    - Time: 15 minutes

- Vacuum Bag Lamination (Uncured Silicone to Primed Foil)
    - Temperature: 100°C
    - Pressure: 14.7 psi

- Time: 15 minutes
  - Notes:
    - Laminate entrapped air must be completely removed
    - Substrate surfaces must be completely mated
    - Utilize proper press pads in a platen press process
    - Time equals the time that the polymer is at temperature

- Recommended Foil Prime Coat:
  - Application method: Pneumatic spray or lint free rag wipe
  - Primer: 2:1 vol --- Anhydrous Isopropanol:DC2260
    - Note: Primer ratio is subject to change based on application method
  - 30 minute hydrolization step, at 23°C and 50% RH, after priming

- Recommended Laminate Post Cure:
  - Oven is vented and mechanically circulating
    - Air exchange rate: ~ 2 cubic feet of fresh air per minute per pound of silicone.
  - Laminate thickness < 0.060” = 2 hr at 204°C
  - Laminate thickness 0.060” to 0.150” = 4 hr at 204°C
  - Laminate thickness > 0.150” (Subject to evaluation)

Conclusion

The 27CR has vastly better thermal stability versus any other alternative flexible heater compounds and coated substrates. The 27CR compound will retain its initial physical properties and most importantly its elasticity longer than competitive materials during field operation. This is true for short term thermal exposure up to 320°C and for long-term thermal aging up to 220°C. 27CR based flexible heater substrates are best in class versus competitive flexible heater substrates in terms of thermal stability.

The 27CR compound can be purchased as bulk compound, CP-27R, or in any calendered construction, ex, 51276R015.

Flexible heater substrate part number (GG)(##)(C)(CO)(TTT)

(GG) Two digit code identifying the substrate [51] = Style 7628 fiberglass
(##) Two digit code identifying the silicone rubber compound [27] = 27CR compound
(C) One digit code identifying the product construction [6] = Cured Side 1 & Uncured Side 2
(CO) One or two letter(s) identifying the product color [R] = Red
(TTT) Three digit code identifying the overall product thickness in mils [015] = 0.015”

Lastly, 27CR coated flexible heater substrates are compatible with many of Arlon’s current flexible heater substrates, and laminates can be effectively built mixing products.

Excellent adhesion can be achieved when laminating calendered substrates, whether an uncured to uncured or a cured to uncured laminate combination is used:

(GG)58(C)R(TTT) to (GG)27(C)R(TTT): 121°C, 50 psi, 15 minutes.
(GG)57(C)R(TTT) to (GG)27(C)R(TTT): 177°C, 50 psi, 15 minutes.
(GG)60(C)R(TTT) to (GG)27(C)R(TTT): 121°C, 50 psi, 15 minutes.

References

[1] Dvonic, P.R. (2004) High Temperature Stability of Polysiloxanes, Silicon Compounds: Silanes and Silicones, Gelest Catalog 3000-A pp. 419-431

[2] QMFZ2.GuideInfo Plastics – Components, UL Online Certification Directory (2007) Retrieved on September 7, 2007 from http://database.ul.com/cgi-bin/XYV/template/LISEXT/1FRAME/showpage.html?&name=QMFZ2.GuideInfo&ccnshorttitle=Plastics++Component&objid=1073827223&cfgid=1073741824&version=versionless&parent_id=1073827222&sequence=1